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Fruitful Examination of STEM Education Over Two Decades: Bibliometric Analysis

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Abstract

This study aims to provide a concise overview of scientific output, prominent researchers, countries, and areas of focus in the field of STEM education research. An examination of the scholarly output in the field of STEM education was conducted using bibliometric methods, focusing on publications published from 2002 to 2023. The methodology employed in this study is a bibliometric analysis technique combined with computational mapping analysis. The tools used are VOSviewer and Rstudio. A total of 25,318 articles were retrieved from the Scopus databases. These papers were published in social sciences, engineering, scientific education, physics, and astronomy journals, among others. The primary results indicate that the number of publications on STEM education has been generally consistent from 2002 to 2023. Co-authorship relationships primarily involve researchers from the same nation. Furthermore, a change in the areas of research focus was noted. Previous research has been extensively conducted in various fields, including the social sciences, engineering, scientific education, physics, and astronomy. A recent study has highlighted the significance of curriculum and curriculum development. In conclusion, research on STEM education still needs to be carried out and developed, especially regarding STEM-based teaching materials.

Keywords: bibliometrics; engineering; STEM education; social sciences

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INTRODUCTION

Implementing Science, Technology, Engineering, and Mathematics (STEM) education through the specialized approach has become more recognized in teaching (Abanoz & Yabaş, 2023; Czoher et al., 2021). The implementation of the Next Generation Scientific Standards (NGSS) allows for the inclusion of Following Era Science Standards as an optional component in scientific education (Abouhashem et al., 2021; Menon & Devadas, 2019). Implementing the Next Generation

Science Standards (NGSS) underscores educational institutions' fusion of technology and science education. When incorporated into the implementation of NGSS, technology design can enhance student motivation, creative thinking skills, and the use of scientific principles in construction. Furthermore, the innovation plan handling plays a crucial role in STEM training (Abdullah et al., 2014; Abina et al., 2023). Designing a plan is a necessary skill for students in technology education.



It is noted that some countries have implemented coordinated processes for planning innovation in science instruction. Many studies above employ diverse research methodologies, including mixed methods, quantitative, and qualitative approaches. Using a mixed-method research approach, several studies have investigated the following aspects: the impact of instructional design on students' situational interest (Duan et al., 2021; Khanaposhtani et al., 2018); students' perceptions of technology (Analytis et al., 2017; Augello et al., 2018); effectiveness; content knowledge (Abas et al., 2019); students' conceptions (Khanaposhtani et al., 2018); and students' ability to handle the complexity of a task (Lexis et al., 2023). Research by Fathurohman et al (2021) produced a high school physics textbook based on STEM Problem-Based Learning on Newton's Motion Laws of Materials and has been proven to be valid, in line with Arief Muttaqin et al., (2020) stated that

it is an integrated science book that combines ethnoscience and STEM, or Ethno-STEM is one of the teaching materials that students currently need to help improve learning outcomes both in terms of knowledge and skills. However, conditions in the field rarely use STEM-based textbooks; other bibliometric research studies also only used VOSviewer, while none use Rstudio. Science mapping is a method that visually represents the connections between different subject areas, materials, or authors within a specific study field. It uses a geographical format to display these linkages (Allendoerfer et al., 2014). Therefore, the study topics were addressed using performance analysis and scientific mapping methodologies. Furthermore, the bibliometric R software was employed to conduct the bibliometric study, whereas VOSviewer was utilized to visually represent the science mapping outcomes.

Table 1 A complete summary of the data analysis as well as the software analysis tool

Research Question	Main Method (Actual Analysis)	Science Mapping Tool
What is the trend in developing citations for publications and papers on STEM education research from 2002 to 2023?	Performance analysis involves examining articles' annual publication count and average citation count.	R package bibliometrix ver. 3.3.0
Which authors and nations had the greatest impact on the publication of articles on STEM education between 2002 and 2023?	Performance analysis involves identifying the most productive authors based on their scientific publications over time and determining the most productive countries.	R package bibliometrix ver. 3.3.0
Which keywords were most significant, and what co-occurrence patterns exist in STEM education research between 2002 and 2023?	Scientific mapping, also known as co-word analysis, is a method used to analyze the relationships between different scientific concepts and terms.	VOSviewer ver. 1.6.16

METHOD

The exponential progress of information technology in the 21st century has resulted in significant improvements in data collection, organization, manipulation, and inference (Chiang et al., 2020). Consequently, there has been

a recent surge in the utilization of bibliometric analysis in scientific education research. Issues such as technology and higher education, engineering design, scientific literacy, project-based learning, STE(A)M, or the

linking behavior in the network of science education research co-authorship, among others, are analyzed using bibliometric methods (Abdullah et al., 2014; Ahmed et al., 2023; Alan et al., 2023; Anabousy & Daher, 2022; Barak & Assal, 2018; Chiang et al., 2020). The adoption of analysis is justified by its ability to identify and delineate collective scientific research subjects and provide a thorough account of scientific outcomes and their progression in the field of study across time (Nugraha et al., 2023). The research focuses on the keyword "STEM Education." Keywords were utilized to designate articles that were deemed pertinent. The abstract and title were criteria for picking articles based on pre-established keywords. The study period included in the evaluation process spanned from 2002 to 2023. On January 10, 2024, a data search was performed

using the Rstudio and VosViewer applications, which resulted in the discovery of 25,318 articles that Scopus indexed. Scopus is an open-source article search platform that indexes article data. It allows users to access articles and citations from diverse sources without any restrictions based on the reputation of the article or its publisher. Once the process of collecting data is finished, the data is stored in two specific file formats, namely *.ris and *.csv. The *.ris format serves as the data mapping format in the R studio and VOSviewer application, while the *.csv format is utilized for data analysis in Ms. Excel. Microsoft Excel is utilized annually to examine development data and arrange articles according to their highest citation count. The study concept and methodology of this paper are illustrated in Figure 1.

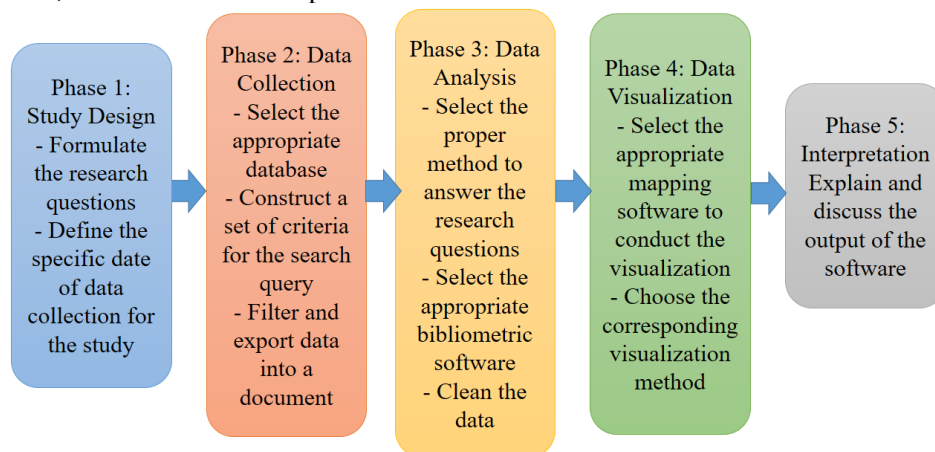


Figure 1 Science mapping workflow using bibliometric analysis

The study utilized the typical methodology for science mapping, as adapted from Assefa and Rorissa's work in 2013. The adaptation is illustrated in Figure 1. The subsequent section presents the phases of Phase 1-4 sequentially, whereas the results section focuses on the research findings. The final portion presents an analysis and discourse on the findings.

RESULTS AND DISCUSSION

Development of Scientific Output on STEM Education Research

Figure 2 illustrates the progression of STEM education research across time. From 2002 to 2023, the number of articles experienced a steady increase until 2022. In 2022, the output of articles reached its peak, with a total exceeding 900 pieces. Moreover, there was a decline in the production of articles in 2023 ($n = 685$) and 2024 ($n = 0$).

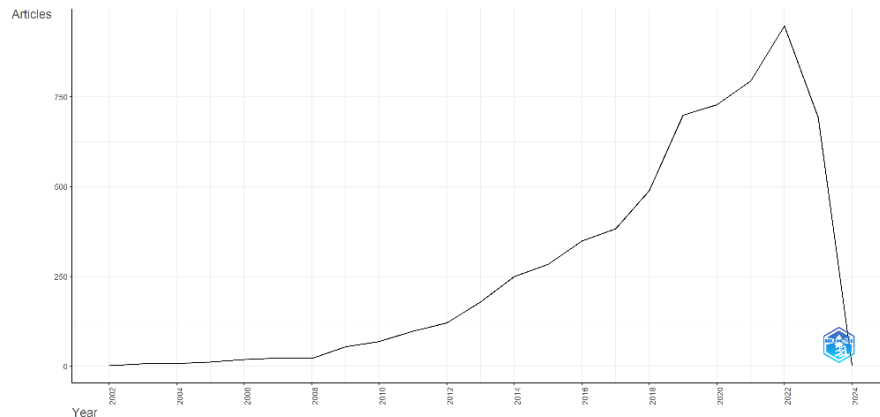


Figure 2 Annual scientific production

Figure 2 shows that out of the total 8,254 authors mentioned in the text, 1,735 produced a minimum of two articles on Stem Education Research between 2002 and 2023. Furthermore, 27 authors contributed to three papers, six authors contributed to four articles, and eight authors contributed to five or more publications. To clarify, the majority of authors published only a total of two publications from 2002 to 2023. In this period, the number of STEM Education publications tends to be stable, with only two articles per year. This shows consistency in research interest and focus

over that period. With only two articles per year, trends may indicate research focus on particular areas or topics within STEM Education (Cahyani et al., 2020). For example, research may focus more on developing STEM teaching methods, curriculum evaluation, or implementing technology in STEM learning (Amiruddin et al., 2022). The average number of quotations per published article was 11.37. On average, each newspaper receives approximately 0.80 quotations every year. The figure displays the average number of article citations each year.

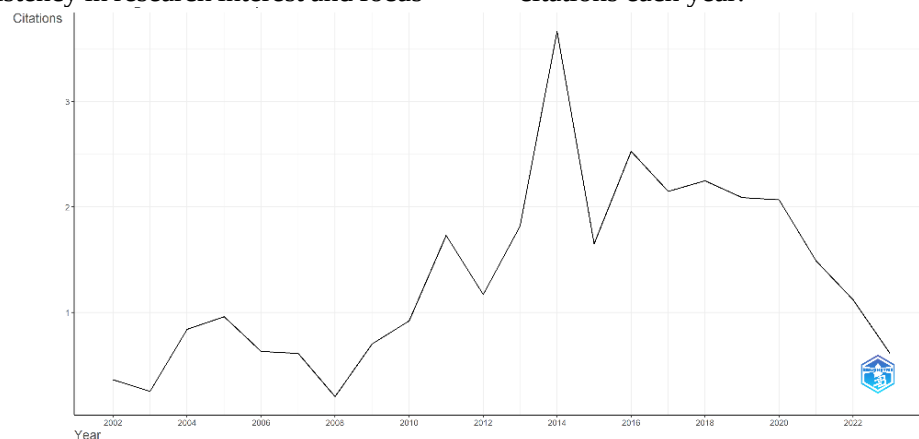


Figure 3 Average article citation per year

Leading Researchers and Countries in Article Publication on STEM Education Research

An additional examination of the most prolific scholars in the field of STEM education was undertaken, focusing on

the number of articles published and citations received between 2002 and 2023. Although several highly active authors have consistently made contributions to the field through publications in the past decade,

reviewing the number of articles published by the most productive scholars can provide an idea of their level of productivity and contribution to generating new knowledge in the field of STEM education (Arianti et al., 2022). Observing the increase or decrease in the number of publications over time can provide insight into the evolution of research interests and the focus on relevant topics (Putri et al., 2021). In addition to the number of articles published, it is also important to evaluate the number of citations that the works of these scholars receive. Citations are an

important indicator of the impact and relevance of their research in the scientific community (I Putu Yogi et al., 2021). Analysis of patterns of citations received can reveal success in influencing and contributing to scientific discussion and thinking in STEM education (Almuharomah et al., 2019). Others have concentrated all of their work within a shorter timeframe, particularly starting in 2019, as depicted in Figure 4. Contrary to (Capraro et al., 2016), who are listed as the corresponding authors, no works have been published by them since 2022.

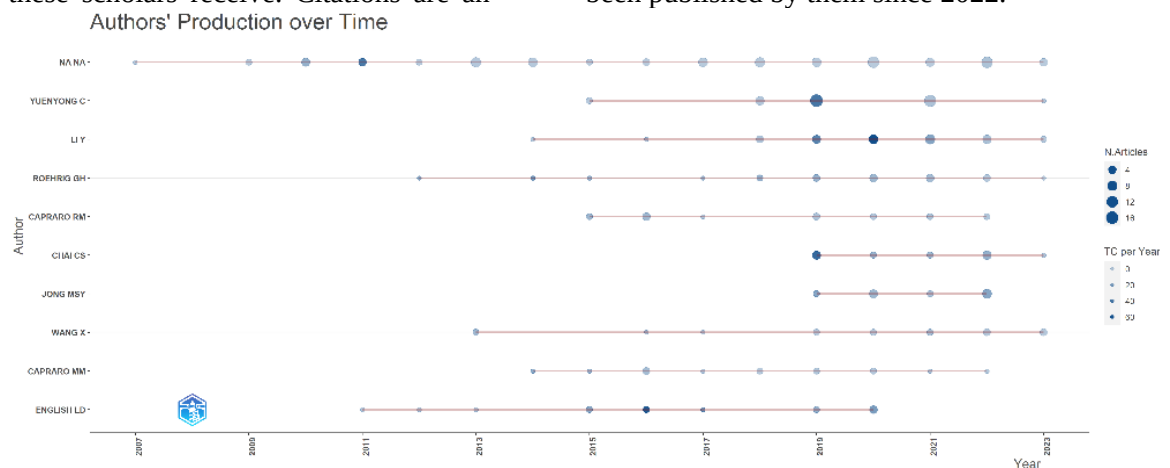


Figure 4 Top authors' production over the time

Given that the total number of citations in Figure 4 includes citations from outside the STEM education research area, it is important to determine the most important articles for the STEM education research community. This can be done by analyzing the number of times other authors cited a particular article in the dataset within the same collection, which is referred to as the number of local citations. A comprehensive analysis was also performed on the authors' nations involved in the study, along with the tally of publications from single and multiple countries (Amiruddin et al., 2022). Although some authors may have notable productivity peaks over certain periods, it is important to evaluate the consistency of their contributions over

longer periods. Understanding whether consistent patterns in their research productivity can provide insight into the sustainability and seriousness of their commitment to STEM education (Cahyani et al., 2020). Through additional examination, we can attempt to identify factors that may have contributed to the success of the most productive scholars in STEM education fields (Amiruddin et al., 2022). These can include factors such as collaboration with other researchers, access to resources and support, the superiority of the research methodology or approach, and personal factors such as motivation, dedication, and courage to explore new fields (Almuharomah et al., 2019). This was done to provide a concise overview of the

countries contributing to the scientific discourse on STEM education research.

The analytical findings are displayed in Figure 5a and Figure 5b.

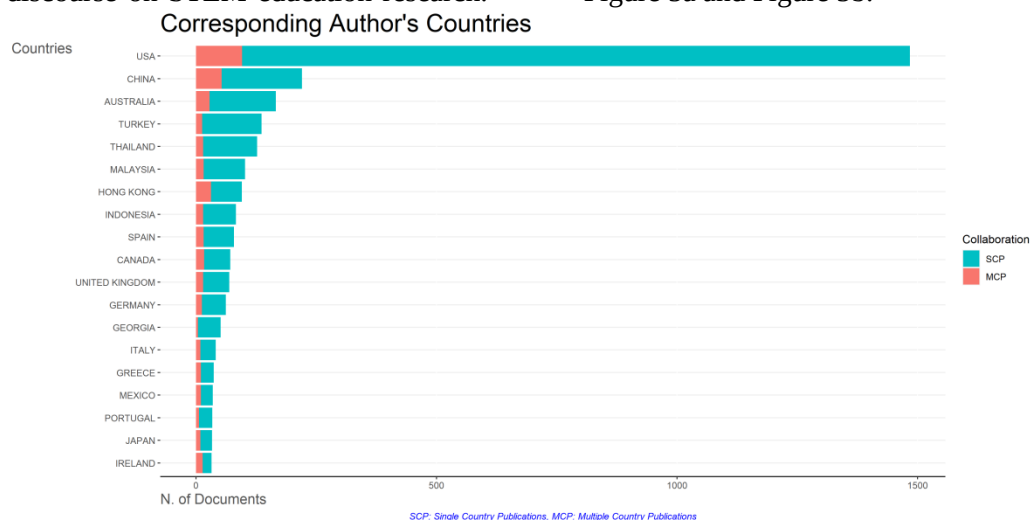


Figure 5a Corresponding author's country

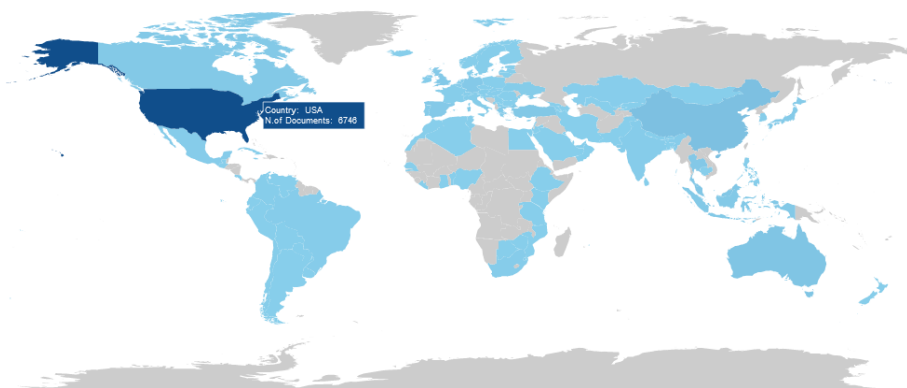


Figure 5b Corresponding author's country

Figure 5a and Figure 5b show that the top 10 publishers are comprised of countries from the USA, Asia, Australia, and Europe. Numerous writers from diverse regions have mostly researched STEM education. Specifically, the preponderance of papers on STEM education was authored by corresponding authors from the United States, totaling 1388 articles, which accounts for over one-fifth of the inspected publications. In addition, the proportion of publications involving multiple countries was only 6.5%. China has the highest proportion of publications involving numerous countries, at 24.1%, followed by the UK at 21.7%, Germany

at 19.4%, and Indonesia at 18.1%. The fact that most papers on STEM education come from authors associated with the United States indicates the country's prominence in research and publications in the field (Dewi & Jauhariyah, 2021). This can be caused by various factors, including the number of quality higher education institutions and research institutions, large investments in research and development, and adequate infrastructure to support research activities (Mahjatia et al., 2021). These findings highlight the importance of further development in STEM education research in Indonesia. With the proportion of publications involving

many countries still low, there is an opportunity to increase international collaboration in STEM education research in Indonesia. This can be done by building collaborative networks with researchers and institutions from other countries and increasing investment in research and the development of basic education (Putri & Dwikoranto, 2022). These findings demonstrate the limited scope of stem education research in Indonesia and emphasize the need for its further development (Nugraha et al., 2023).

Keyword Co-Occurrence Patterns in STEM Education Research According

The VOS viewer software was employed to visually represent the outcomes of the

co-word analysis. The software produced a two-dimensional map by computing a similarity matrix derived from a normalized co-occurrence matrix. In order to acquire the comprehensive data, terms extracted from the titles of the articles, the abstracts, and the author keywords have been incorporated in the co-word analysis. However, only terms that appeared in at least three articles for the co-word analysis were considered. Out of the total of 1390 keywords, only 131 met the criterion. Consequently, two terms ("students" and "education") that had poor relevance value and did not provide any extra material were carefully removed. Consequently, there were 129 terms left for mapping. The entire co-word network is seen in Figure 6.

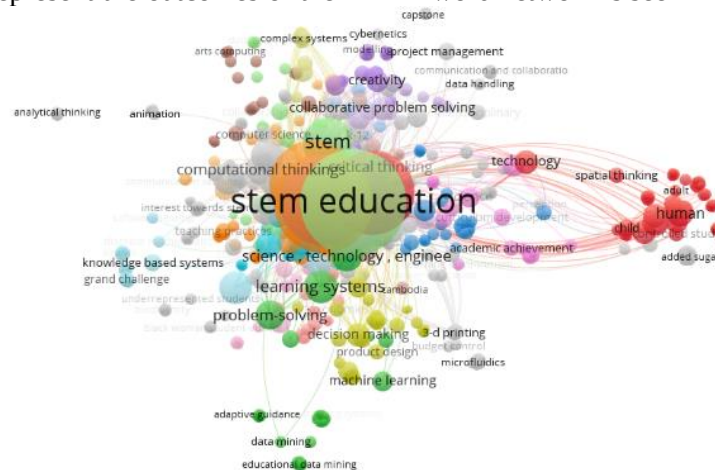


Figure 6 Final visualization of co-word analysis

In Figure 6, the font size indicates the relative frequency of term occurrence, while the connecting lines denote keyword co-occurrence. Term clusters that exhibit frequent recurrence are emphasized using a consistent color scheme. The co-word analysis uncovers multiple clusters that are not mutually exclusive. The green and red clusters are the main focal points on the map. The largest cluster, known as the green cluster, comprises eleven phrases, including "stem education," "collaborative problem solving," "computational thinking," and "learning

system," among others. The field of STEM education research encompasses a wide range of interconnected concepts, and the study of co-occurring phrases does not clearly identify distinct clusters.

STEM education is the predominant focus in learning, with social sciences, engineering, and instructional science significantly impacting research areas. As a result, several researchers have incorporated multiple elements while studying STEM education (Abanoz & Yabaş, 2023; Czoher et al., 2021). The opening part emphasizes the extensive research efforts in STEM education since

the 2000s. Various research fields have significantly contributed to understanding the essence of STEM education, and scholars have used multiple teaching methods to enhance students' STEM education (Abouhashem et al., 2021; Al-Qassar et al., 2021; Menon & Devadas, 2019). The co-word analysis results reveal multiple clusters encompassing diverse research focus aspects.

CONCLUSION

Ultimately, the findings of this study have the potential to enhance advancements in the field of STEM education and inspire scholars to explore new areas of focus and engage in international collaboration. This work has been motivated by the extensive literature on STEM education. The aim is to offer a comprehensive overview of the current state of scientific research in this field and to explore its transition towards an emerging state. This research has limitations in data interpretation; the results of bibliometric analysis can be limited by how the data is analyzed and interpreted. Sometimes, analysis results may vary depending on the parameters used or the visualization method chosen, which can result in different interpretations. Future research could focus on validating bibliometric analysis results by other means, such as surveys or interviews with experts in the field of STEM Education. In addition, a qualitative approach can also be used to provide a more in-depth interpretation of the results of bibliometric analysis.

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